Surface Waves and Turbulence

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LONG-TERM GOALS

To improve our understanding of radar backscatter and of thermal and microwave emission from the ocean surface, and of relevant physical processes including surface turbulence, mixing and convective heat transport.

SCIENTIFIC OBJECTIVES

To investigate the dynamics of turbulent convection near the ocean surface, and of breaking waves, including microbreakers, and the role of bubbles in turbulent mixing.

BACKGROUND

Among the most important processes affecting the transfer of heat in the upper 1-100 cm of the ocean are the circulating motions with horizontal axes aligned in the wind-direction, known as Langmuir circulations (1, 2, 3). These may occur on large (1-60 m) scales and also on scales of 1 cm or less (4) particularly near the crests of steep wind waves. The presently available theories of Langmuir circulations (5, 6, 7, 8, 9) associate them with short-crested surface waves. However, some recent laboratory experiments by Melville et al. (4) on the initial surface disturbances due to a turbulent wind show that circulating cells of Langmuir type make their appearance before the surface waves are of any significance. This raises the question whether, in these experiments, the surface waves were really necessary; could the Langmuir cells have arisen without them? The wind certainly generates a surface shear flow, so the question is whether such a shear flow by itself is stable or unstable to roll-like disturbances. Linearised (small perturbation) theory suggest that it is. However a theory for nonlinear initial perturbations (such as might be produced by a turbulent wind) has not yet been given.

METHOD OF APPROACH

The author's main approach is to construct dynamical models on the basis of the Navier-Stokes equations or, when viscosity is negligible, the Euler equations of motion. If thermal effects are significant, Boussinesq-type equations may be used. Comparison with observation is emphasized. Where possible, experiments are conducted to verify theoretical results and obtain new information.

RESULTS

The author has developed a nonlinear theory for the instability of a free-surface shear flow to streamwise vortices, which is based on the so-called "energy method" (10, 11, 12). This has recently been applied by Poje and Lumley (13) to turbulent flows over a rigid surface, but is here adapted to a

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free surface and to laminar flow, as in the experiments of Melville et al. (4). There is no need to parameterise the turbulence by eddy-coefficients, etc. Moreover a direct comparison with experimental data is possible. It is found that for any given spacing L of the rolls there is a series of possible modes of instability, each member of the series having a corresponding number m of cells in the vertical direction. Modes 1 and 2 are illustrated in Figures 1 and 2 respectively. The lowest mode (m=1) is the most unstable. For each mode there is a critical Reynolds number for instability. At Reynolds numbers exceeding this critical value the rate of growth is a function of the wavenumber 2?/L, and there exists one wavenumber for which the growth rate is a maximum.

Comparisons have been made with recent laboratory experiments (4, 14,) and reasonable agreement is found. In these experiments, initial surface waves also were observed, but their RMS slopes were demonstrably too small to have a significant effect on the initial growth of the rolls. On the other hand, the rolls affected the surface waves strongly at a later stage of their development.

Breaking waves. Some progress has also been made in applying the method of Balk (15) to the problem of the initial stages of wave breaking in a modulated wave group. This new method relies on a Langrangian formulation of the equations of motion which is more natural and has some advantages over the presently used Hamiltonian equations. Balk's equations have been successfully programmed and applied to a particular initial disturbance having 2 waves in a group. The results are being studied and extended.

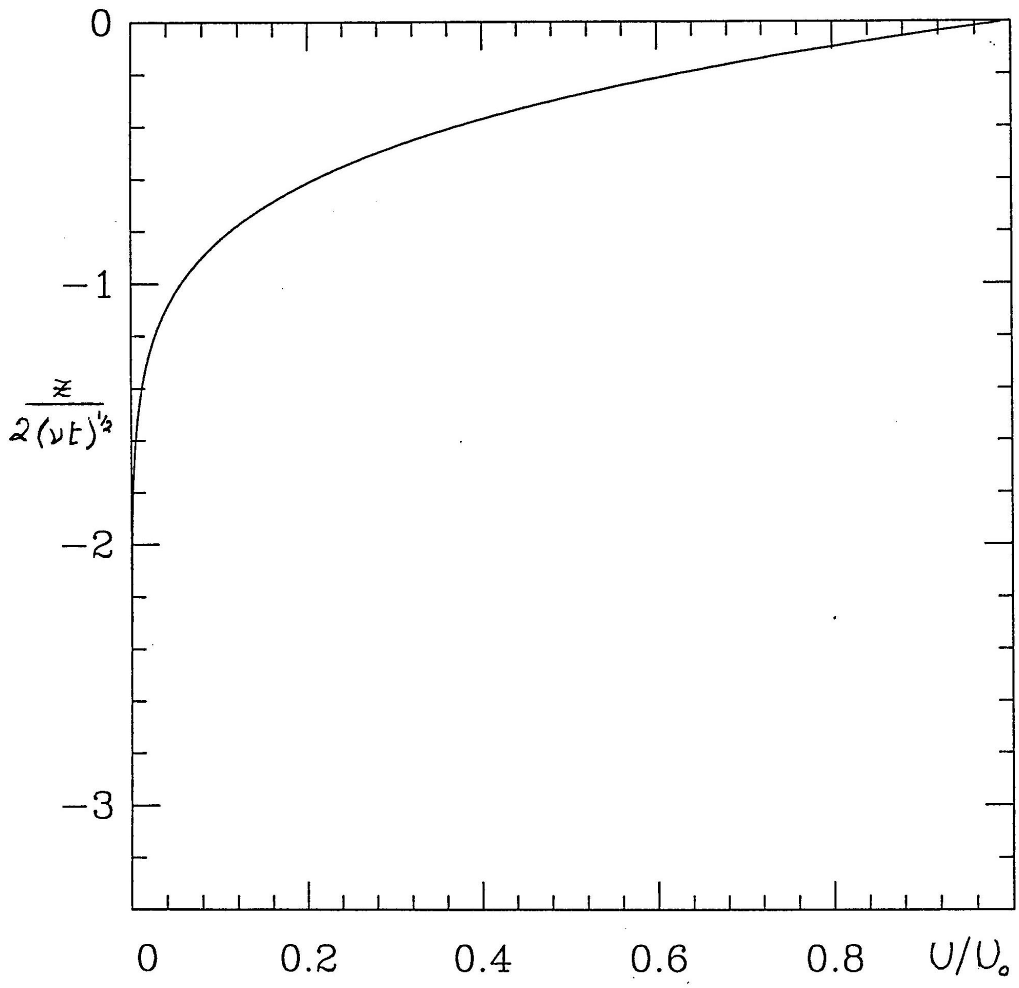

Figure 1. The unperturbed velocity profile corresponding to the experiments of Melville et. al. (1998). z, ? and t denote the vertical coordinate, the kinematic viscosity and the time, respectively. U0 is the horizontal velocity at the surface; U0 = At where A is a constant acceleration.

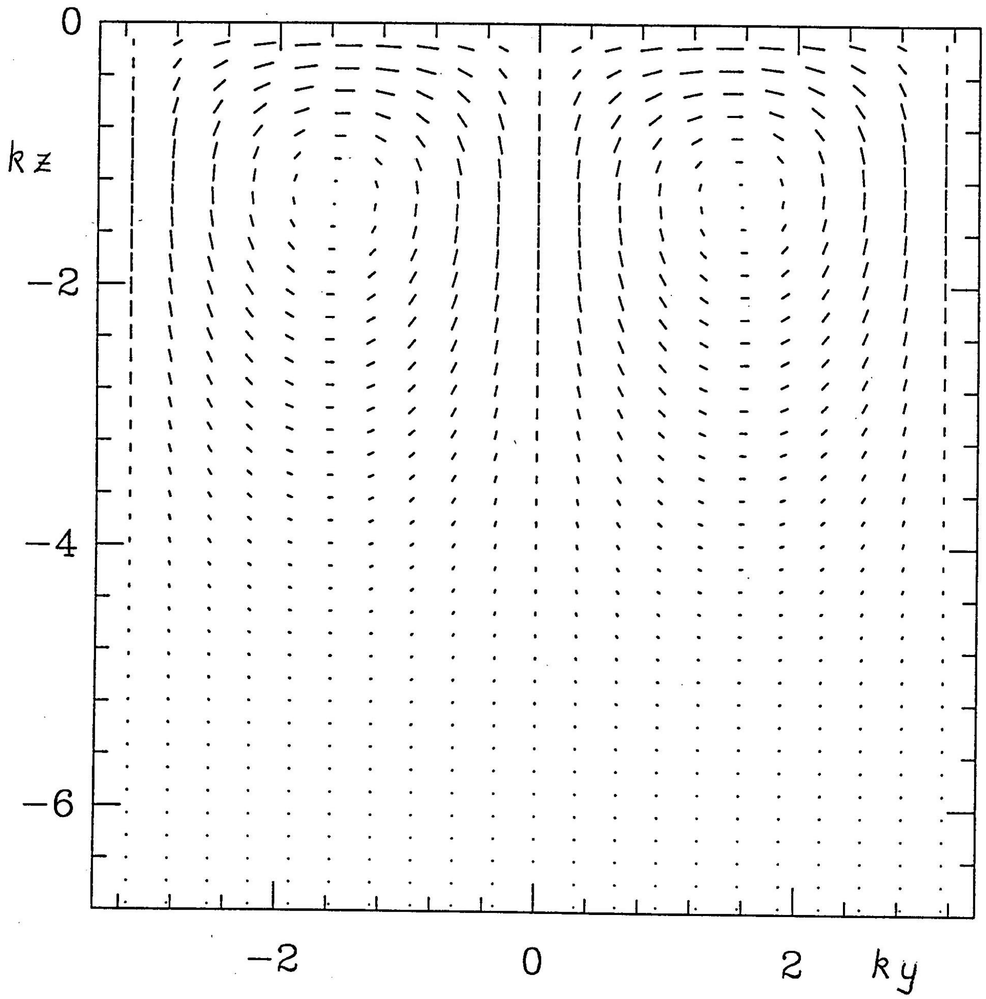

Figure 2. The roll instability of the shear flow in Figure 1, as shown by the velocity vectors in a vertical, cross-stream plane. Typical case (m = 1).

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STATISTICAL INFORMATION

Published papers

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2. Longuet-Higgins, M.S., 1998 "Instabilities of a horizontal shear flow with a free surface," J. Fluid Mech. 364, 147-162 .

3. Longuet-Higgins, M.S., 1998 "Viscous streaming from an oscillating spherical bubble," Proc. R. Soc. Lond. A 454, 725-742.

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7. Longuet-Higgins, M.S., "Solitary waves on deep water", (12 pp.) in Proc. I.M.A. Conf. on Wind-over-Waves Couplings," Oxford Univ. Press, Oxford, England, in press.

8. Longuet-Higgins, M.S., The instability of a free-surface flow to streamwise vortices. Submitted.

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PRESENTATIONS

1. "The dynamics of bubbles and turbulence in the uppermost layer of the ocean." Seminar, Dept. of Physical Oceanography, C.I.C.E.S.E., Ensenada, Mexico, 16 October 1997.

2. "Instabilities of a horizontal shear flow with a free surface." Lecture, ONR Workshop on Free-Surface and Wall-Bounded Turbulence, Cal. Inst. Tech., Pasadena, 26-28 February 1998.

3. "On bubbles and turbulence in the uppermost layers of the ocean." Invited lecture, Hopkins Conf. on Environmental Fluid Mechanics, Johns Hopkins Univ., Baltimore, 2-4 April 1998.

4. "Three-dimensional instabilities of waves and shearing currents." IUTAM Symp. on Three-Dimensional Aspects of Air-Sea Interaction, Nice, France, 17-21 May 1998.

5. "The instability of a free-surface shear flow to streamwise vortices (Langmuir circulations)." Wind-over-Waves Workshop, Imperial College, London, 20 October 1998.

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